Fermilab/BD/TEV
Beams-doc-467
March 3, 2003

Chromaticity, Tune, and Coupling Drift and Snapback Correction Algorithms in the Tevatron

J. Annala, M. Martens
Fermilab, Beams Division

Introduction

Drifts in the chromaticity, tunes, and coupling are observed in the Tevatron at 150 GeV. A snapback effect of these parameters is also observed at the start of the Tevatron energy ramp. Without compensation the chromaticity changes by ~50 units, the tunes by ~0.01 units, and the coupling by ~0.02 minimum tune split over about 2 hours while the Tevatron is at 150 GeV. By applying a time varying corrections to the Tevatron trim magnets we are able to compensate for the drifts and reduce their magnitude to ~2 units in the chromaticity, ~0.002 units in the tune, and ~0.003 units in the minimum tune split.

The known cause of the chromaticity drift and snapback is the time varying sextupole fields from persistent currents in the Tevatron dipole magnets. The magnitude of this drift and snapback has been measured and an algorithm was developed to compensate for these drifts by applying a time varying current to the sextupole corrector magnets. The algorithm is implemented in hardware via an applications program called TCHROM that calculates time varying functions and loads the Tevatron hardware with the appropriate settings.

In Collider Run II, tune and coupling drifts at 150 GeV and the corresponding snapback at the start of the Tevatron energy ramp are also observed. After making measurements to quantify the magnitude of these drifts, additional hardware was installed to compensate for the tune and coupling drifts and the applications program TCHROM was expanded to include the tune and coupling drift algorithms.

This note documents the algorithms used for the drift and snapback corrections and gives a sketch of the hardware involved. The chromaticity compensation has been used since at least Run I. The tune and coupling drift compensation was commissioned on 9/23/02 during Collider Run II.

b_2 Correction Algorithms used in TCHROM

The current supplied to the chromaticity sextupole magnets is the sum of two terms: 1) a term to set the desired chromaticity (this includes compensation for the geometric and hysteretic b_2 in the dipoles, and the natural chromaticity) and 2) a term to compensate for the time dependence and snapback of the b_2 component of the Tevatron dipoles. The current for the first term is controlled with the CAMAC 467 cards labeled T:SF and T:SD. The current for the second term, the time dependent portion, is controlled with the CAMAC 465 cards labeled C:SFB2 and C:SDB2. The voltage outputs of these cards are summed together to provide a reference voltage for the SF and SD power supplies. A sketch of the hardware hookup is shown in

Figure 1.

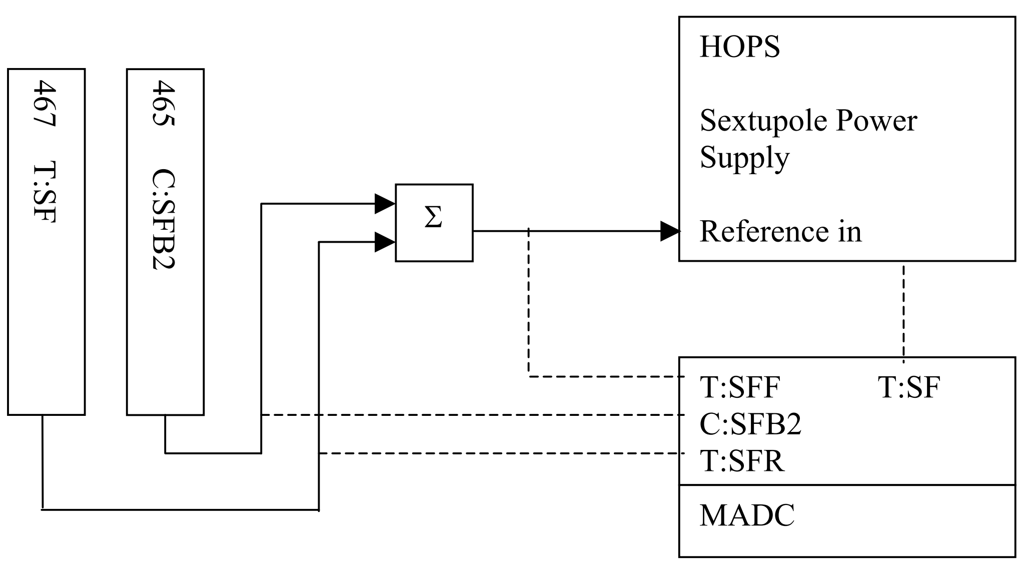


Figure 1 Sketch of the installation at the C3 house for controlling the SF chromaticity sextupole correction power supply. The reference voltage from the T:SF card and the C:SFB2 card are added together with a summing module. The output of the summing module is input to the power supply controller for the SF circuit. A similar hookup exists at the C4 house for the SD magnets.

The sextupole current for the first term is loaded into the T:SF and T:SD CAMAC cards through the applications program C49 that controls most of the major circuits in the Tevatron. The sextupole current for the time dependence term is loaded into the C:SFB2 and C:SDB2 CAMAC cards via the open access client (OAC) program called TCHROM. The choice of algorithms is based on magnet and beam based measurements and is not discussed here. Instead we limit ourselves to documenting the algorithm that is used.

The sextupole current loaded into the 465 CAMAC cards labeled C:SFB2 and C:SDB2 uses the formula

Equation 1 $$I_{SF} = \xi + -3.31*(150/1000)*< b_2> \rightarrow I_{SFB2} = -0.4965*<b_2>$$

Equation 2 $$I_{SD} = \xi = -5.1*(150/1000)*< b_2> \rightarrow I_{SDB2} = -0.765*<b_2>$$

where $<b_2>$ is a function of time.

The functional form of $<b_2>$ depends on the history of the Tevatron ramp and the state of the Tevatron ramp. The parameters relevant to the history of the Tevatron ramp are: the time spent at flattop, T_{FT}; the time spent on the back porch, T_{BP}; and time spent on the 150 GeV front porch before accelerating, T_{FP}. The states of the Tevatron where the $<b_2>$ compensation is applied are: the 150 GeV front porch, the acceleration ramp, the deceleration ramp, and the 150 GeV back porch.

We list the functional form for $<b_2>$ in each of these cases:

On the Front Porch

On the Front Porch $<b_2>$ has the form

Equation 3 $$<b_2> = b_{2i} + m * \ln(t + c)$$

where t is the time (in seconds) since the start of the 150 GeV front porch. The terms in Equation 3 are calculated as

Equation 4 $$b_{2i} = -0.04 * \ln(T_{BP}/60) - [0.161 - (0.0277 * \ln(T_{BP} /60))] * \ln(T_{FT})$$

Equation 5 $$m = 0.342 - 0.0208*[2*\ln(T_{BP}) - \ln(T_{FT})]$$

Equation 6 $c = 0$

where T_{FT} is the number of seconds spent on the previous flattop, and T_{BP} is the number of seconds spent on the previous back porch.

On the Back Porch

On the Back Porch $\langle b_2 \rangle$ has the form

Equation 7 $\langle b_2 \rangle = b_{2i} + m * \ln(t + c)$

where t is the time (in seconds) since the start of the 150 GeV back porch. The terms in Equation 7 are calculated as

Equation 8 $b_{2i} = 0.082 * \ln(T_{FT})$

Equation 9 $m = -0.196 - 0.024 * \ln(T_{FT})$

Equation 10 $c = 20$ seconds

where T_{FT} is the number of seconds spent on the previous flattop, and T_{BP} is the number of seconds spent on the previous back porch.

The Acceleration Ramp (snapback or unwind)

The snapback that occurs at start of the Tevatron energy ramp (event $42) has a polynomial form

Equation 11 $\langle b_2 \rangle = b_{2,start} \, [1-(t/T_{chrom})^2]^2$

Where $b_{2,start} = \langle b_2 \rangle$ at the time of the start of the Tevatron energy ramp and T_{chrom} is the snapback time constant which is currently set to

Equation 12 $T_{chrom} = 6$ seconds.

The value of $b_{2,start}$ for the acceleration ramp is equal to the value of $\langle b_2 \rangle$ in Equation 3 at the time $t = T_{FP}$. The value of T_{FP} is calculated just before the start of the Tevatron ramp and TCHROM recalculates Equation 11 and loads the values into hardware.

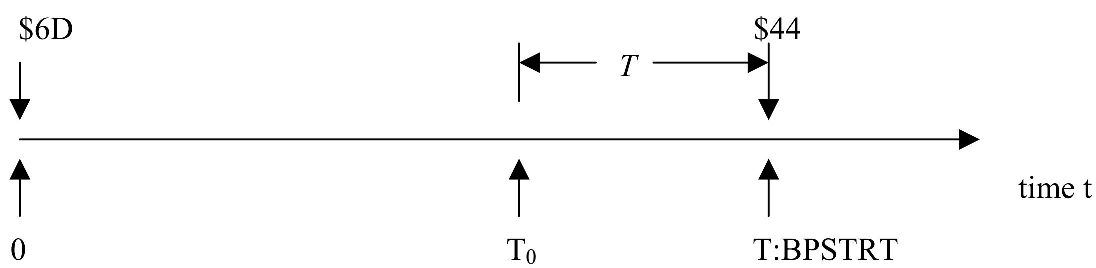
The Deceleration Ramp

The deceleration ramp has a time table that starts at zero and ends up at b_2 at the start of the back porch. The reason for this ramp is to smoothly connect the back porch table with the deceleration ramp. This ramp is triggered by event $6D and the final value for the ramp is b_2 (t=0) for the back porch H-table (this is not b_{2i} on the back porch - we will call this value b_{2f}). The only parameter that will be an input to the time table calculation will be the ramp length (*T*).

In order to calculate the table, the OAC needs to know the length of the deceleration ramp (T:BPSTRT). The time ramp should be all zeros until time = (T:BPSTRT - *T*) (we will call this time T_0). From time t = T_0 until t = T:BPSTRT the time table will be calculated as

Equation 13 $$b_2 = b_{2f}\,(t-T_0)^2 / T^2$$

This diagram describes the times involved in this calculation. $6D is defined to occur at time 0.



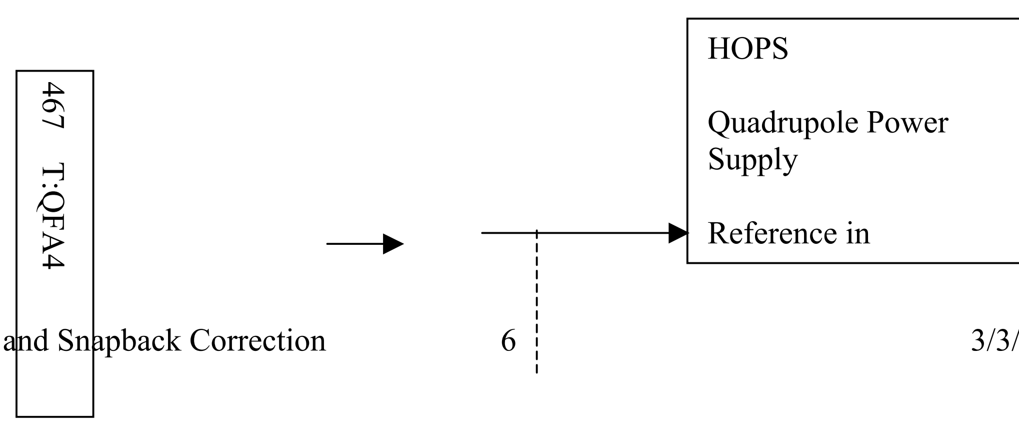
Test mode loading of the sextupoles can be done by setting a value to T:CHRCOM. Setting this device will force a download of the B2 devices as if the proper state change had taken place. The values to load specific ramps are:
1 ->load front porch curve, 2 -> load unwind (snap back) curve, 3 -> load back porch match curve, 4 -> load back porch curve, 5 -> clear load status

Tune and Coupling Drift Compensation Algorithms for TCHROM

The current supplied to the tune and coupling trim circuits is the sum of two terms: 1) a term to set the desired tunes and coupling, and 2) a term to compensate for the time dependence and snapback of the tune and coupling. The current for the first term is controlled with the CAMAC 467 cards labeled T:QFA4, T:QDD1, T:SQ, and T:SQA0. The current for the second term, the time dependent portion, is controlled with the CAMAC 465 cards labeled C:QFB2, C:QDB2, C:SQB2, and C:SQ0B2. The outputs of these cards are summed together to provide a reference voltage for the QFA4, QDD1, SQ, and SQA0 power supplies. A sketch of the hardware hookup is shown in

Figure 2.

The new summing modules have a long term drift of not more than 100 ppm ($\pm$0.01%), and the absolute accuracy of the output no worse than $\pm$0.1%). The modules in C3 and C4 take twinax as one of the inputs signals, and the summed output. The other input, and the output to the MADC are limo. Staying with this configuration is not necessary, as long as we make up the correct jumper cables so the new modules can plug right in at C3 or C4.



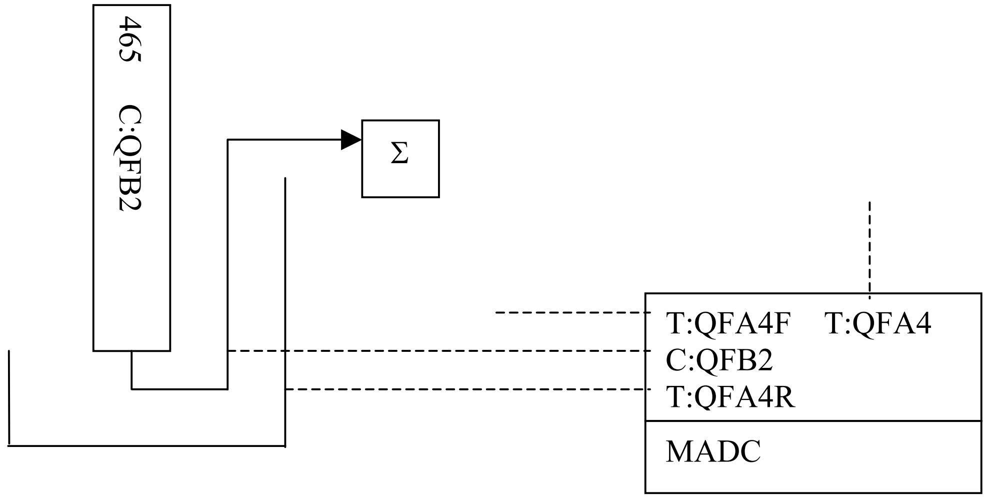


Figure 2 Sketch of the installation at A4 house for controlling the QFA4 trim quadrupole power supply. The reference voltage from the T:QFA4 card and the C:QFB2 card are added together with a summing module. The output of the summing module is input to the power supply controller for the QFA4 circuit. A similar hookup exists for the QDD1 (at the D1 house), the SQ (at the B2 house), and the SQA0 (at the A4 house) magnets.

The quadrupole current for the first term is loaded into the T:QFA4, T:QDD1, T:SQ, and T:SQA0 CAMAC cards through the applications program C49 that controls most of the major circuits in the Tevatron. The quadrupole current for the time dependence term is loaded into the C:QFB2, C:QDB2, C:SQB2, and C:SQ0B2 CAMAC cards via the open access client (OAC) program called TCHROM. The choice of algorithms is based on beam measurements and is not discussed here. Instead we limit ourselves to documenting the algorithm that is used.

The currents loaded into C:QFB2 and C:QDB2 are determined from the tune shift compensation using the formula

Equation 14 $$I_{QFB2} \text{ (in Amps)} = (10.747) * \langle\Delta\nu_x\rangle + (2.797)\langle\Delta\nu_y\rangle$$

Equation 15 $$I_{QDB2} \text{ (in Amps)} = (-2.746) * \langle\Delta\nu_x\rangle + (-10.28)\langle\Delta\nu_y\rangle$$

where the tunes, $\langle\Delta\nu_x\rangle$ and $\langle\Delta\nu_y\rangle$, are functions of time which are given below.

The currents loaded into C:SQB2 and C:SQ0B2 are determined from the coupling shift compensation using the formula

Equation 16 $$I_{SQB2} \text{ (in Amps)} = (9.47) * \langle\Delta\kappa_{SQ}\rangle + (0.00) * \langle\Delta\kappa_{SQ0}\rangle$$

Equation 17 $$I_{SQ0B2} \text{ (in Amps)} = (0.00) * \langle\Delta\kappa_{SQ}\rangle + (122.0) * \langle\Delta\kappa_{SQ0}\rangle$$

where the coupling, $\langle\Delta\kappa_{SQ}\rangle$ and $\langle\Delta\kappa_{SQ0}\rangle$, is a function of time which are given below. (Note: Even though some of the constants in the above equations are zero, they may change to some non-zero value in the future, which explains why they are included in the equations.)

In general the functional form of the drifts depends on the history of the Tevatron ramp and the state of the Tevatron ramp. However we currently implement the tune and coupling compensation only on the front porch and acceleration ramps. Also, we do not consider the variation of tune drift as a function of ramp history. Instead we assume that the Tevatron front porch has been preceded by a dry squeeze sequence (typically between 15 and 30 minutes) that is currently used before a shot setup.

There are several different time dependent functions of the tune and coupling compensation depending on the state of the Tevatron. In general there will be 1) a function of time at 150 GeV on the front porch, 2) an unwind (snap back) at the start of acclereration, 3) decleration ramp, and 4) a back porch ramp. These are the same ramps as the b2 unwind correction and we will use the same functional form for both the b2 corrections and the tune and coupling corrections.

For the tune and coupling corrections only the front porch and unwind have a ramp which will be used. The other ramps will be added when pbar deceleration is implemented.

We list the functional forms in the following sections:

On the Front Porch

On the front porch the tune and coupling corrections have the form

Equation 18	$<\Delta\nu_x> = n_{xi} + m_x * \ln(t + c_x)$
Equation 19	$<\Delta\nu_y> = n_{yi} + m_y * \ln(t + c_y)$
Equation 20	$<\Delta\kappa_{SQ}> = n_{SQi} + m_{SQ} * \ln(t + c_{SQ})$
Equation 21	$<\Delta\kappa_{SQ0}> = n_{SQ0i} + m_{SQ0} * \ln(t + c_{SQ0})$

where t is the time (in seconds) since the start of the 150 GeV front porch. The terms in Equation 18 through Equation 21 are calculated as

Equation 22	$n_{xi} = -0.00778$	$m_x = +.0019$	$c_x = 0.0$
Equation 23	$n_{yi} = +0.0127$	$m_y = -0.0031$	$c_y = 0.0$
Equation 24	$n_{SQi} = 0.0250$	$m_{SQ} = -0.0061$	$c_{SQ} = 0.0$
Equation 25	$n_{SQ0i} = 0.0$	$m_{SQ0} = 0.0$	$c_{SQ0} = 0.0$

(Note: Even though some of the constants in Equation 22 through Equation 25 are zero they may change to some non-zero value in the future which explains why they are included. Also, in future versions of TCHROM the constants in Equation 22 through Equation 25 may depend on the time spent at flattop or the time spent on the back porch. For now these constants are valid when a shot setup is preceded by a 15-minute dry squeeze cycle of the Tevatron magnets.

The Acceleration Ramp (snapback or unwind)

The unwind that occurs at the start of the ramp (event $42) is a time table that begins at a value which is equal to the value of the front porch ramp (the H-table) just before the ramp. Each of the 4 parameters, $<\Delta\nu_x>$, $<\Delta\nu_y>$, $<\Delta\kappa_{SQ}>$, and $<\Delta\kappa_{SQ0}>$, has their own time table. The only parameters that are input to these time table calculations are the starting values and the duration of the time table ramp. For the tune correction the duration of the time table is T_{tune} and for the coupling correction the duration of the time ramp is T_{coup}. These may be different from each other and from the duration of the time table for the chromaticity correction T_{chrom}. For now these times are set to

Equation 26 $\quad T_{tune} = 6$ seconds

Equation 27 $\quad T_{coup} = 6$ seconds

The snapback that occurs at start of Tevatron energy ramp (event $42) has a polynomial form

Equation 28 $\quad <x_2> = x_{2,start}\,[1-(t/T)^2]^2$

where $<x_2>$ represents one of the variables $<\Delta\nu_x>$, $<\Delta\nu_y>$, $<\Delta\kappa_{SQ}>$, and $<\Delta\kappa_{SQ0}>$, $x_{2,start} = <x_2>$ at the time of the start of the Tevatron energy ramp and T is the time constant for the snapback. The time constant $T = T_{tune}$ for $<\Delta\nu_x>$, $<\Delta\nu_y>$ and $T = T_{coup}$ for $<\Delta\kappa_{SQ}>$, and $<\Delta\kappa_{SQ0}>$.

The value of $x_{2,start}$ for the acceleration ramp is equal to the value of $<x_2>$ in Equation 18 through Equation 21 at the time $t = T_{FP}$. The value of T_{FP} is calculated just before the start of the Tevatron ramp and TCHROM recalculates Equation 28 and loads the values into hardware.

Deceleration Ramp
and Back Porch

For now the tune and coupling drift compensation are not implemented for the deceleration ramp an the back porch. These ramps will be implemented when pbar deceleration is implemented.